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Abstract

THE IRRADIATION BEHAVIOUR OF URANIUM AND URANIUM ALLOY FUELS

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Basic mechanisms for the two irradiation induced phenomena of growth and swelling have recently been proposed at Harwell. Growth is ascribed to the selective condensation of vacancies and interstitial atoms in preferred crystallographic planes under the anisotropic thermal expansion stresses in the "fission spikes", and it has been deduced that growth effects persist to higher temperatures with increasing fission rate. It has been proposed that swelling due to irradiation-produced inert gases in uranium is governed largely by surface diffusion of the metal atoms, which allows the bubbles to migrate bodily and to collide and coalesce with one another. Theories based on this mechanism can account for breakaway swelling and grain boundary phenomena and do not require any re-solution of the inert gases.

During capsule irradiation tests, pure uranium swelled badly in the temperature range 500-650°C. Small additions of carbon, molybdenum and aluminium reduced the swelling, while iron, chromium, titanium and niobium had no significant effect. The lowest swelling occurred in "adjusted" uranium, i.e. the U.K.A.E.A. Springfields Factory product containing 200-500 ppm iron, 500-1200 ppm aluminium and 300-1200 ppm carbon, beta-quenched and alpha-annealed to achieve small random grains which minimise irradiation growth and surface wrinkling. It contained a fine intermetallic precipitate, primarily $UA1_2$. After comparable irradiations the gas bubbles were much smaller and more numerous than those in pure uranium, and since the pressure in small bubbles is high, the volume increase was less. The fine precipitate is believed to be responsible for the small bubble size and superior swelling resistance, probably by preventing the migration of the bubbles. The thermal cycles to be expected in

a "Magnox" reactor do not affect the swelling resistance of "adjusted" uranium.

Enhanced swelling, due to large grain boundary fissures, was observed in alpha-uranium irradiated at 400-500°C and at fission rates of 15 MW/t or more. This has been called enhanced grain boundary swelling and is believed to be due to irradiation growth stresses probably acting in conjunction with the grain boundary bubbles to produce large tears. "Adjusted" uranium was again found to be superior to pure uranium in resisting this effect, which is not significant at the low fuel ratings used in the "Magnox" reactors as the growth stresses do not persist to sufficiently high temperatures.

Uranium/plutonium/molybdenum alloys irradiated in the gamma-phase at 600°C showed increasing swelling with increasing plutonium or decreasing molybdenum content. However, although the swelling was low compared with pure uranium, the best uranium/plutonium/molybdenum alloy was inferior to "adjusted" uranium.

It is concluded that "adjusted" uranium shows excellent resistance to irradiation growth and swelling which it achieves with only minor additions and without the large nuclear and chemical processing penalties associated with more highly alloyed uranium. It is considered that the irradiation characteristics of this "adjusted" uranium will not limit the life of the present "Magnox" fuel below 5000 MWd/t average.